ESTABLISHING EXPOSURE LIMITS FOR ULTRAVIOLET RADIATION

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INTRODUCTION

The International Non-Ionizing Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA) has recently proposed a set of guidelines for maximum personnel exposure to ultraviolet radiation (UVR). This paper will discuss the basis for these guidelines. The guidelines cover occupational and general population exposure to optical radiation within the wavelength range of 180 nm (the edge of the vacuum ultraviolet) to 400 nm (the edge of the visible spectrum). UV laser radiation is not covered by this proposal. Some of the underlying assumptions of the UVR guidelines may be invalid for highly monochromatic laser radiation.

BIOLOGIC EFFECTS OF UVR

The UVR spectrum is frequently divided into three spectral bands for ease in discussing biologic effects and health protection standards. As with any such spectral band scheme, the dividing lines are not truly fine lines. These bands (from the CIE) are: UV-C from 100 nm to 280 nm, UV-B from 280 nm to 315-320 nm, and UV-A from 315-320 nm to 380-400 nm. Relatively low irradiances of UV-C and UV-B radiation can cause photokeratitis ("welder's flash") and erythema ("sunburn") if delivered over a period of hours. Far greater irradiances of UV-A are required to cause these effects--often leading to the mistaken impression that UV-A radiation is harmless. Chronic exposure to UVR, especially UV-B, is known to cause accelerated skin aging, skin cancer and lenticular opacities (cataract), as well as other ocular effects. The widespread use of UVR in industry includes many new applications in photoresist processes, photocuring and welding; and UVR is used in cosmetic tanning, dermatology, and dentistry. This increased use necessitates the development of exposure limit guidelines for UVR.

GUIDELINES ON LIMITS OF EXPOSURE TO UVR

In recommending exposure limit (EL) guidelines, the INIRC was well aware of the great difficulties of deriving a generally applicable set of limits for this part of the optical spectrum. Firstly, it is generally recognized that UVR has beneficial health effects as well as adverse effects. The limits are not meant to preclude the beneficial use of UVR in medicine (nor elective UVR exposures for cosmetic purposes which normally exceed the EL guidelines). Secondly, skin sensitivities to UVR exposure vary enormously with racial factors and skin pigmentation for both acute and chronic effects. UVR irradiances which may not affect some individuals may be a hundredfold above levels which may affect sensitive skin.

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Photosensitization resulting from pharmaceuticals, chemicals and systemic disease states make some individuals extremely sensitive to UVR. The geometry of exposure and the wearing of hats and other apparel also greatly affect the likelihood of adverse effects resulting from a given exposure dose. While chronic exposure to UVR is known to cause skin cancer, it is extremely difficult to quantify a threshold exposure below which there is no risk of carcinogenesis. When considering all of these factors, it is quite necessary that the guidelines be applied intelligently by professionals with a knowledge of these controlling factors. The EL's certainly cannot be considered as fine lines between safe and hazardous exposure conditions.

For acute affects it is well known that reciprocity exists between irradiance (exposure dose rate) and exposure duration; i.e., the exposure dose required to ellicit a specific biologic effect is constant over a wide range of exposure durations--from microseconds to several hours. Natural biologic repair of injured tissue causes this reciprocity relation to break down for exposures greater than 8-24 hours.

It is generally accepted that the primary UVR interaction mechanism with biological tissue is photochemical. For this reason there can be very significant variations in tissue sensitivity with a change in wavelength. The term "action spectrum" is used to describe the variation in radiant exposure necessary to ellicit a given tissue response as a function of wavelength. When the action spectra for threshold photokerititis and skin erythema are plotted together, it is possible to draw an envelope curve to include both, This approach has been followed in deriving an exposure limit (EL) action spectrum. Figure 1 shows some of the biologic threshold data along with the envelope curve of the guideline EL. A tabulated list of EL values at representative wavelengths in the UV-C and UV-B is provided in Table 1. Of course intermediate values of the EL exist at intermediate wavelengths and may be determined by interpolation. For most broad-band light source spectra (e.g., from lamps and arcs) spectroradiometric data taken at every five to ten nanometers is quite sufficient to calculate permissible exposure durations.

To calculate permissible exposure durations for broad-band sources it is necessary to have a spectral irradiance distribution at the location of the potential exposure. The radiation spectrum is then weighted against the EL envelope action spectral values of S_λ to obtain an effective irradiance, E-eff in W/cm^2:

$$\text{E-eff} = \sum E_\lambda \cdot S_\lambda \, \Delta\lambda \qquad (1)$$

where E_λ is the spectral irradiance in $W/(cm^2 \cdot nm)$ and S_λ is the UVR EL spectral sensitivity function as a function of wavelength λ in nm. The maximum permissible exposure duration in any 24-hour period is then t-max (in seconds) and is the maximum daily exposure at the normalization wavelength of 270 nm (i.e., 0.003 J/cm^2) divided by E-eff in W/cm^2:

$$\text{t-max} = 0.003 \; J/cm^2 / \text{E-eff} \qquad (2)$$

Some judgement of occupancy times and exposure conditions must be made in the proper measurement of irradiation levels and calculations of E-eff and t-max.

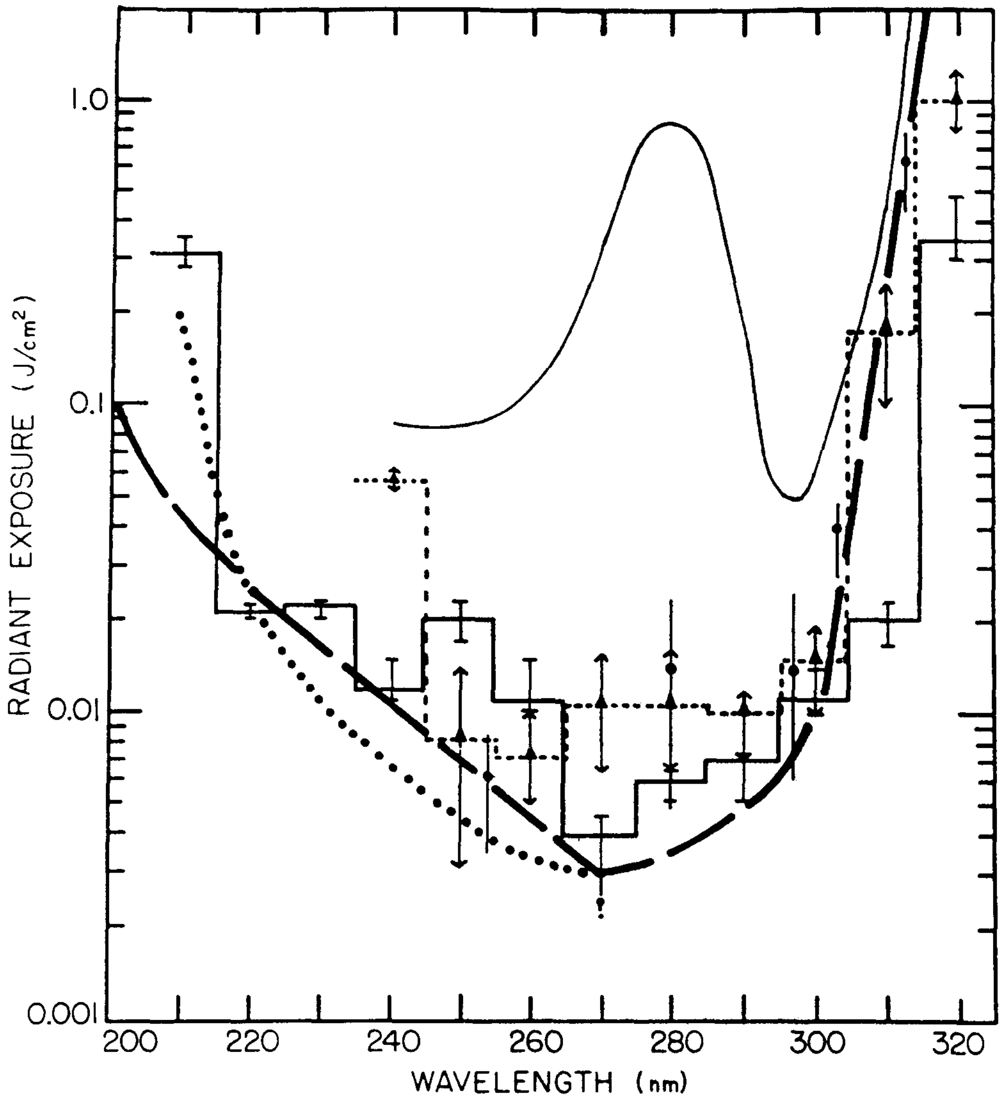

Figure 1. EL Envelope Curve for UV-B and UV-C Wavelengths. The bold dashed line is the EL. The solid curve is the classical erythema curve developed in the 1930's. The dotted-line histogram is threshold erythema; the solid-line histogram is threshold photokerititis. See references for detailed sources of this data.

For UV-A exposures, no spectral weighting function is applied. For wavelengths between 318 nm and 400 nm the EL is 1.0 J/cm^2 for 0.1 µs to 1000 s. The total UV-A irradiance is divided into that EL to determine the t-max for that spectral band, unless the irradiance is less than 1 mW/cm^2, in which case it does not exceed the UV-A EL irradiance for more lengthy periods, i.e., greater than 1000 s.

TABLE 1. Representative EL Values.

Wavelength (nm)	EL (J/m²)	EL (mJ/cm²)	Relative Spectral Effectiveness S_λ
180	2,500	250	0.012
190	1,600	160	0.019
200	1,000	100	0.03
205	590	59	0.051
210	400	40	0.075
215	320	32	0.095
220	250	25	0.12
225	200	20	0.15
230	160	16	0.19
235	130	13	0.24
240	100	10	0.30
245	83	8.3	0.36
250	70	7.0	0.43
254	60	6.0	0.50
255	58	5.8	0.52
260	46	4.6	0.65
265	37	3.7	0.81
270	30	3.0	1.0
275	31	3.1	0.96
280	34	3.4	0.88
285	39	3.9	0.77
290	47	4.7	0.64
295	56	4.6	0.54
297	65	6.5	0.46
300	100	10	0.30
303	250	25	0.19
305	500	50	0.060
308	1,200	120	0.026
310	2,000	200	0.015
313	5,000	500	0.006
315	10,000	1,000	0.003
316	15,000	1,500	0.002

CONCLUSIONS

While some difficulties remain to be resolved to achieve UVR exposure guidelines, this IRPA/INIRC effort has generally been met with a favorable response. Hopefully an approved guideline EL will be approved during 1984 and you may expect to see it published in the Health Physics Journal within 12 months.

REFERENCES

1. IRPA/INIRC, Draft Guidelines on Limits of Exposure to Ultraviolet Radiation of Wavelengths Between 180 nm and 400 nm (Incoherent Optical Radiation), INIRC Secretariat, Fontenay-aux-Roses, March 1983.

2. Sliney, D. H., and M. L. Wolbarsht, Safety with Lasers and Other Optical Radiation Sources, Plenum Publ. Corp., New York, 1980.